Technical Paper 11 For 2d and 3d eds. see next papers.

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

THE USE OF MICE AND BIRDS FOR DETECTING CARBON MONOXIDE AFTER MINE FIRES AND EXPLOSIONS

BY

GEORGE A. BURRELL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1912

Generated on 2024-09-28 10:56 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

CONTENTS.

	Page.
Introduction	3
Occurrence of carbon monoxide	5
Properties of carbon monoxide	6
Physiological effect of carbon monoxide	6
Chemical tests for carbon monoxide	8
The use of mice and birds	8
Experiments with mice	8
Experiments with birds	10
Summary	11
Relative susceptibility of men and birds	12
Conclusion	15
Publications on mine accidents and tests of explosives	15

Generated on 2024-09-28 10:55 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

THE USE OF MICE AND BIRDS FOR DETECTING CARBON MONOXIDE AFTER MINE FIRES AND EXPLOSIONS.

By GEORGE A. BURRELL.

INTRODUCTION.

In connection with its investigation of the causes of mine fires and explosions the Bureau of Mines is making a careful study of the methods that can be used with greatest efficiency for exploring mines containing smoke or suffocating or poisonous gases.

The presence of that poisonous gas, carbon monoxide (white damp), in the afterdamp of explosions and fires in mines has caused the death of a great many miners. An inspection of the reports of those explosions and mine fires in which men have been killed shows that this gas is often the cause of the majority of the fatalities. Haldane [a] makes the statement that carbon-monoxide poisoning is responsible for nearly all the fatalities. After a recent disaster at a mine in Pennsylvania in which 21 men were killed the bodies of 17 men showed no such marks of violence as would be produced by the concussion of an explosion. Tests of blood from some of these bodies clearly showed the bright pink hue caused by carbon monoxide. Not only have men present in mines at the time of disasters succumbed to this gas, but rescuers endeavoring to save their unfortunate comrades have perished also.

Of the gases produced in mines, carbon monoxide is the most feared and the most difficult to detect. A miner's lamp gives warning of almost every dangerous condition of the atmosphere in a mine except the presence of this gas. Percentages of methane below those that form explosive mixtures can be detected by the appearance of the "cap" of the lamp flame, and a deficiency of oxygen is shown by the smothering of the flame in time for a retreat to be made before bodily harm can result. Carbon monoxide, however, may be present in deadly quantities in an atmosphere without the safety lamp detecting it, because a proportion much below that required to give a cap on a lamp flame is extremely poisonous.

Other gases occasionally found in mines in harmful quantity, such as hydrogen sulphide, and oxide of nitrogen fumes can be detected

[a] Foster, C. LeN., and Haldane, J. S. The investigation of mine air. 1905. P. 144.

Generated on 2024-09-28 10:59 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

even in great dilution by their odor, so that fatalities from the presence of these gases in mines are few.

The author tested the value of a wick flame as a detector of carbon monoxide in comparison with its value as a detector of methane. A Wolfe safety lamp, constructed so that prepared mixtures of air and carbon monoxide could be fed into it at the base, was used. The minimum percentage of carbon monoxide (about 2 per cent) required to produce a visible cap was found to be almost identical with the required proportion of methane. Two observers could detect no difference in the color or the height of the caps produced by this percentage of either gas. Neither could they when 3 per cent of either gas was used.

In a mine some observers, especially after becoming accustomed to the darkness ("getting eyesight," as it is termed), may detect a cap when the air contains less than 2 per cent of methane, and it is possible to detect less than 2 per cent of methane by the use of special testing lamps. But the point brought out by the author's experiments is that low percentages of either methane or carbon monoxide scarcely give caps that distinguish one gas from the other. Moreover, it has been the author's experience that when a given percentage of carbon monoxide is present in the air of a coal mine, a larger percentage of methane is usually present, so that this gas would interfere with the detection of carbon monoxide by a lamp even if carbon monoxide enough to give by itself a characteristic cap were present. It is also true that in the afterdamp of mines carbon monoxide in quantity sufficient to produce a cap usually accompanies a deficiency of oxygen and an excess of nitrogen, so that the lamp is extinguished before it can show a cap. One result of this last fact, however, is that the indications of a lamp may sometimes prevent a man from going into an atmosphere containing carbon monoxide enough to be rapidly poisonous.

The gases that come out of the crevices in the coal bed immediately after shots of explosives may contain much carbon monoxide and hydrogen, besides methane, and when a lamp is held close to the crevices the carbon monoxide and hydrogen may cause the cap of the lamp flame to differ somewhat from the cap produced by methane alone. In exploring mines, however, the great danger to a rescue party is from small proportions of carbon monoxide—proportions so small that they have no visible effect upon the flame.

The author is aware that some mining men are of the opinion that a percentage of carbon monoxide below that which is immediately dangerous perceptibly brightens or lengthens the flame of a lamp, but he knows of no characteristic of carbon monoxide that would warrant such an opinion. A possible explanation of the brightening or lengthening, suggested by J. W. Paul, mining engineer of this

Generated on 2024-09-28 10:55 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

bureau, lies in the fact that a party exploring a mine containing afterdamp sometimes enters a place in which the proportion of oxygen in the air is larger than it was in the place previously explored, and as a consequence the wick flame burns for a while with increased intensity. As the oxygen content of an atmosphere decreases, the flame of an oil lamp burns more dimly until, at 17 or 17.5 per cent of oxygen, the flame is extinguished.

OCCURRENCE OF CARBON MONOXIDE.

Carbon monoxide has not been positively identified in the samples of what may be termed normal mine air collected by this bureau, except in samples collected at the working faces where the air was vitiated by powder smoke. Samples of mine air from the ventilating current, from the main returns, and from splits have been examined, also samples from inclosed areas in which the air had been still; but although the apparatus used was accurate to 0.02 per cent, the author can not state positively that carbon monoxide was present in any of the samples. A series of tests is now being conducted in which air from sealed bottles containing coal that was freshly mined at the time of bottling is being examined for minute quantities of combustible gases other than methane. Although about 12 examinations have been made of samples taken one week apart, the presence of carbon monoxide has not been positively determined.

It appears that carbon monoxide is produced in mines in harmful quantity only through the agency of heat or by the incomplete combustion of carbon that attends explosions, mine fires, the use of explosives, etc. The gas is produced by the imperfect combustion and dry distillation of coal dust in explosions, by the imperfect combustion of methane, by the burning of wood and coal with insufficient supply of oxygen, and by the contact of previously formed carbon dioxide with red-hot carbon, as when the flame of a blast or a gas explosion is projected into an atmosphere filled with the fine coal dust. The last-named cause operates toward the formation of carbon monoxide when those explosives that contain within themselves sufficient oxygen for the complete oxidization of their carbonaceous components are used in breaking down coal.

The carbon monoxide formed, with hydrogen and methane, collects in the open spaces and crevices behind a standing shot, and the miner is often burned by the flame that bursts forth when he carelessly puts his lamp close to a crevice or into an open space to examine the effect of a blast. Besides the danger that attends the burning of these crevice gases, trouble is often experienced from the gases that result from the use of improperly handled explosives in ill-ventilated parts of a mine. A series of experiments is being carried on by the Bureau of Mines to determine the gases that are produced by the firing of

Generated on 2024-09-28 10:57 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

different explosives and the extent to which the use of the explosives vitiates the air of the working places.

PROPERTIES OF CARBON MONOXIDE.

Carbon monoxide is a colorless and inodorous gas with a specific gravity of 0.967. A liter of it weighs 1.2506 grams at 0° C. and 760 mm. pressure.[a] It will not support combustion, but burns with a pale blue flame. The lambent flame above a grate in which anthracite or coke is burning is due to the combustion of this gas. Carbon monoxide is the main combustible ingredient of water gas, of producer gas, and of blast furnace gas, which contain approximately 15 to 40 per cent of it, and is present, but in smaller proportion, in illuminating gas made by the destructive distillation of coal. It has not been identified as a constituent of the samples of natural gas examined by the Bureau of Mines, a fact that accounts for natural gas being less poisonous than water gas, producer gas, or ordinary illuminating gas. Carbon monoxide in mixtures with air has a wide range of explosibility, from 16.5 per cent gas, lower limit, to 74.95 per cent gas, higher limit.[b] Methane has explosive limits that lie between about 6.1 per cent gas, lower limit, and 12.8 per cent gas, higher limit.[c] The lower limits cited have reference to complete combustion and to the ignition of the gas by an electric spark. Other modes of ignition, changes in temperature, the shape of the containing vessel, differences in pressure, and the presence of more or less water vapor may change the range of explosibility somewhat. The addition of a large quantity of carbon monoxide to explosive mixtures of methane and air would have the tendency to widen the upper limit of explosibility over that of methane alone.

PHYSIOLOGICAL EFFECT OF CARBON MONOXIDE.

The oxygen absorbed from the air in the lungs is normally taken up by the blood in the form of a loose chemical combination with the red coloring matter (hæmoglobin) of the corpuscles, and in this form it is carried to the tissues where it is used. Hæmoglobin not only combines with oxygen but also forms a far more stable compound with carbon monoxide and when saturated with the latter it can not take up oxygen. Hence, when the corpuscles in the blood of a living animal are saturated with carbon monoxide they can not carry oxygen from the lungs to the tissues, and death must result. According to Haldane,[d] carbon monoxide has no other effect than that resulting from its interference with the oxygen supply of the tissues, and apart

[a] Rayleigh. Proc. Royal Soc. London. Vol. 62, 1897, p. 204.
[b] Jour. Soc. Chem. Ind. Vol. 21, 1902, p. 395.
[c] Idem.
[d] Jour. Physiology. Vol. 18, 1895, pp. 200, 430, 463.

Generated on 2024-09-28 11:00 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

from its property of combining with hæmoglobin it is physiologically indifferent, like nitrogen.

The affinity of carbon monoxide for hæmoglobin is about 250 [a] times as great as the affinity of the latter for oxygen. However, if oxygen is administered to a person not too far overcome it will completely replace the carbon monoxide in the hæmoglobin. In this respect pure oxygen acts about five times as rapidly as normal air, which contains approximately 21 per cent of oxygen. From air containing very small percentages of carbon monoxide, less than 0.1 per cent, the blood of a man does not take up enough of the gas to cause distress unless the man breathes such air a long time. If the air contains larger proportions, the blood sooner or later reaches that stage of partial saturation with carbon monoxide that produces helplessness. Haldane [b] makes the following observation:

> The blood of a man will take up about two pints of CO or oxygen. A man at rest breathes about 10 or 12 pints of air per minute, and experiment shows that of the carbon monoxide inhaled about 60 per cent is absorbed by the blood. If a man would breath air containing 0.1 per cent of carbon monoxide he would absorb 0.007 pint per minute. It would then take him nearly 2.25 hours to absorb a whole pint or produce one-half saturation of the blood, at which stage the limbs would become so weak as to cause them to give way when an effort was made to walk. A man who is walking, however, breathes about three times as much air as a man who is at rest, hence he might absorb a pint within an hour. With 0.2 per cent of carbon monoxide the time would be one-half as long, with 0.3 per cent, one-third as long, etc.

If a man who has breathed mine air containing carbon monoxide and has retired to fresh air to recuperate, again enters workings containing this gas before the carbon monoxide has entirely been displaced from his blood, he feels the effects of the gas in less time than when he entered the workings before.

The experience of those who have been partly poisoned by carbon monoxide seems to teach that usually much pain or distress does not precede collapse. One of the first symptoms is weakness of the limbs and dimness of eyesight. For some time after resuscitation, however, there may be severe headache, or even epileptic seizures and other serious ailments.

Poisoning by carbon monoxide can take place very suddenly. For instance, a man in a mine may quickly pass from a place containing such a small quantity of the gas that he has experienced no distress into a place containing a larger quantity where, because of the already partially saturated condition of the blood, he will quickly succumb. Also, the action of the poison may be accelerated by increased exertion, such as climbing a steep incline or ladder, or lifting heavy weights.

---

[a] Haldane, J. S., Causes of death in colliery explosions and underground fires. Report to the Secretary of State for the Home Department. 1896.

[b] Idem, p. 17.

Generated on 2024-09-28 11:05 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

CHEMICAL TESTS FOR CARBON MONOXIDE.

The author has by the aid of a portable gas-analysis apparatus made tests of the air in mines after explosions and fires and has thus ascertained on the spot the composition of the atmosphere in the workings. Because of the time required to make such tests and the need of the services of a person with some knowledge of gas-analysis apparatus, chemical tests of the atmosphere in a mine immediately after a disaster are not made as often as they should be. Another reason for omitting them is that quick chemical tests for small quantities of carbon monoxide are not made as successfully as are chemical tests for methane, carbon dioxide, and oxygen.

Perhaps the best chemical test for carbon monoxide, in that other gases do not interfere and very simple apparatus is required, is by the use of blood diluted with water to a buff-yellow tint. .This test, in the author's experience, is capable of distinctly showing as little as 0.03 per cent of carbon monoxide in the atmosphere. The method of procedure is as follows:

One or two drops of blood drawn from the finger are diluted with water until equal portions of the solution placed in 100 c. c. test tubes have a buff-yellow color. One of the tubes is taken into the mine, and at the place where the air is to be tested about 50 c. c. of the blood solution is poured out, the mine air taking its place. The tube is then corked, taken to the surface, and gently shaken for 10 minutes. If the air contained carbon monoxide the pink color caused by the presence of carbon monoxide hæmoglobin is detected by comparing the solution with the normal blood solution in the other tube.

A fresh active solution of cuprous chloride may be used instead of blood for examining air for carbon monoxide. According to the author's experience, the use of such a solution, if the apparatus is precise and is properly manipulated, will show proportions of carbon monoxide harmful to a rescue party.

THE USE OF MICE AND BIRDS.

EXPERIMENTS WITH MICE.

In the author's opinion the use of birds and mice is superior to chemical tests for carbon monoxide in that the test is quickly made, requires no technical experience, and is sufficiently exact.

Two or three mice or small birds can be placed in a cage and carried into the mine with an exploring party. Because the rate at which chemical changes occur in them is enormously greater than it is in a man, they show symptoms of poisoning far sooner. Haldane [a] states that a mouse weighing one-half an ounce consumes about 15 times as much oxygen as one-half ounce of the human body would consume in

[a] Colliery Guardian, vol. 98, Dec. 17, 1909, p. 1251.

Generated on 2024-09-28 10:55 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

the same time. With 0.1 per cent of carbon monoxide in the air, Haldane found that about two hours elapsed before giddiness, etc., began to appear in a man at rest, and, according to an analysis of the blood, exposure for another half hour would have sufficed to produce practical disablement. A mouse became giddy in 10 minutes. With 0.6 per cent of carbon monoxide in the air, all of the animals tried became helpless in two minutes and rapidly became comatose or died, whereas a person breathing the mixture was entirely unaffected even after 10 minutes. An examination of this person's blood showed that it was one-fourth saturated.

In experiments at the laboratory of the Pittsburgh station of the Bureau of Mines white mice were placed in air containing the following percentages of carbon monoxide: 0.16 per cent, 0.2 per cent, 0.33 per cent, 0.46 per cent, 0.37 per cent, and 0.77 per cent. The mice were placed under a tight glass bell jar having a capacity of 10 liters, into which carbon monoxide had previously been introduced. The atmosphere inside the jar was thoroughly mixed and sampled twice during the experiment, the samples being taken from different points in order to make sure that the content of carbon monoxide was uniformly distributed. The samples were analyzed by combustion of the carbon monoxide in an apparatus with which duplicate analyses agreeing within 0.01 per cent could be performed.

An analysis of the air in the jar at the end of one hour showed that the oxygen content had been depleted 1 per cent, due to the breathing of the mouse, or not enough to affect the air. In air containing 0.16 per cent of carbon monoxide, a mouse showed signs of sluggishness in about six minutes, but this sluggishness, judged by outward manifestations, did not increase to any great extent up to the time the mouse was taken from the jar two hours later. The animal's rate of breathing had dropped from a normal of 160 respirations to about 120 respirations per minute. The mouse did not evince such signs of distress as would serve, if the mouse were carried into an atmosphere containing carbon monoxide, to indicate in one hour's time the presence of 0.1 per cent of the gas.

In air containing 0.2 per cent of carbon monoxide a mouse suffered partial collapse in 15 minutes and showed decided symptoms of distress in eight minutes. At the end of an hour it had not lost all muscular power. It died in two hours.

In air containing 0.31 per cent of carbon monoxide a mouse suffered partial collapse in seven and one-half minutes and showed decided symptoms in about four minutes; but 35 minutes had elapsed before it lost all muscular power and ability to turn over when placed on its back. After removal from the bell jar, the mouse was seemingly in normal condition again in about two hours.

In air containing 0.46 per cent of carbon monoxide a mouse gave decided signs of distress in two minutes; staggered around and showed

Generated on 2024-09-28 10:56 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

partial collapse in four minutes; and in six minutes had lost all muscular power.

In air containing 0.57 per cent of carbon monoxide a mouse showed decided symptoms of distress in one minute, partly collapsed in two minutes, lost all muscular power in seven minutes, and died in 16 minutes.

In air containing 0.77 per cent of carbon monoxide a mouse showed distinct signs of distress in one minute. It lost all muscular power in five and one-half minutes and died in 12½ minutes.

The experiments showed that in air containing the smaller percentages of carbon monoxide the mice displayed varying degrees of activity up to the time they exhibited pronounced distress. Of course, the value of the tests in exploring mines depends upon the warning that the mice give while they are being affected by the carbon monoxide, and it is especially desirable that their actions should indicate the presence of extremely small proportions of carbon monoxide, so that men will have ample time to retire from an atmosphere that contains such proportions of the gas. In the experiments it was found that in small quantities of gas and under like conditions, one mouse might clearly exhibit signs of distress whereas another might become comatose without showing distress so distinctly. Consequently, in using the test, the mouse should be closely watched, and a man not wearing breathing apparatus should retire at once from any part of a mine where the atmosphere distresses a mouse. It is advisable to carry at least three mice at a time into a mine, and to prod them slightly if they remain too quiet, in order to observe them in action.

A man when he exerts himself by carrying heavy objects, climbing ladders, or running consumes in a given time more oxygen and also more carbon monoxide than when he rests. Consequently, a man at work might feel symptoms of carbon-monoxide poisoning that would not be clearly shown by a mouse confined in a cage in the same atmosphere. In an atmosphere containing the small quantities of carbon monoxide usually found in mines after explosions and mine fires, a person may be able to go a long distance without experiencing much inconvenience. On the return trip, however, the symptoms may become so aggravated that considerable difficulty may be experienced in getting to the base of operations or to the surface.

EXPERIMENTS WITH BIRDS.

Because mice may be slow in responding to the presence, in the mine air, of such small percentages of carbon monoxide as would cause distress to a man at work, experiments similar to those performed with mice were tried with birds. Canaries were confined in a bell jar in atmospheres containing the following percentages of carbon monoxide: 0.09 per cent, 0.12 per cent, 0.15 per cent, 0.2 per cent, and 0.29 per cent.

Generated on 2024-09-28 10:55 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

After an exposure of one hour to an atmosphere containing 0.09 per cent of carbon monoxide, a bird was not affected to such an extent that it would, if carried into a mine, indicate by its actions the presence of that proportion of carbon monoxide. Only by close observation could one detect that the bird at the end of an hour felt slightly distressed.

With 0.12 per cent of carbon monoxide in the atmosphere of the bell jar, a bird did not show clearly symptoms of being affected. In about 15 minutes it had lost its liveliness and thenceforth remained comparatively quiet. The bird did not fall from the perch, but close observation showed that it was decidedly weaker at the end of the hour than was the bird placed in air containing 0.09 per cent of carbon monoxide.

In air containing 0.15 per cent of carbon monoxide, a bird evinced symptoms of slight distress in three minutes. It gasped, gradually became weaker, swayed, and at the end of 18 minutes fluttered from the perch. At the end of an hour it had not lost all muscular power, but showed symptoms of extreme weakness.

In air containing 0.2 per cent of carbon monoxide, a bird showed pronounced signs of distress in one and one-half minutes; it became very unsteady in three minutes, and fell from the perch in five minutes. After it was taken from the jar it regained its feet in two minutes and appeared to be in normal condition in five minutes.

In air containing 0.29 per cent of carbon monoxide, a bird fell from the perch in two and one-half minutes. When placed in fresh air again it had almost revived in five minutes.

SUMMARY.

The following table shows the relative susceptibilities of mice and canaries to carbon monoxide poisoning:

Effect of CO on mice and canaries.

Mice.		Canaries.	
Per cent CO.	Effect.	Per cent CO.	Effect.
0.16	Very slight distress at end of hour.....	0.09	Very slight distress at end of hour.
.2	Distress in 8 minutes; partial collapse in 15 minutes.	.12	Weaker at end of hour than after exposure to 0.9 per cent.
.31	Distress in 4 minutes; collapse in 7½ minutes; lost muscular power in 35 minutes.	.15	Distress in 3 minutes; fell from perch in 18 minutes.
.46	Distress in 2 minutes; collapse in 4 minutes.	.20	Distress in 1½ minutes; fell from perch in 5 minutes.
.57	Distress in 1 minute; collapse in 2 minutes; muscular power lost in 7 minutes; death in 16 minutes.	.29	Fell from perch in 2½ minutes.
.77	Distress in 1 minute; muscular power lost in 6½ minutes: death in 12½ minutes.	.....	

These tests show that canaries may be better than mice as indicators of the presence of noxious gases in the atmosphere of mines, since they more quickly show signs of distress in the presence of small

Generated on 2024-09-28 11:07 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

quantities of carbon monoxide. In addition the symptoms of poisoning in birds are much more clearly defined. A bird sways noticeably on its perch before falling and its fall is a better indication of danger than is the squatting, extended posture that some mice assume without much struggling, attempts to walk, or other preliminary symptom of poisoning. Consequently birds not only give more timely warning of the presence of small quantities of carbon monoxide, but exhibit symptoms that are more easily noticed by exploring parties.

RELATIVE SUSCEPTIBILITY OF MEN AND BIRDS.

In order to determine for himself the relative susceptibility of men and birds to the action of carbon monoxide, the author performed the following experiment:

A gas-tight chamber, having a capacity of 80 cubic feet, was constructed. Into this chamber sufficient carbon monoxide was introduced to produce an atmosphere containing 0.25 per cent of the latter. The author entered this atmosphere, taking with him canary birds and pigeons. The canary birds evinced distress in one minute and fell from their perches in three minutes. The pigeons only showed slight signs of distress in 11 minutes. The author remained in the atmosphere for 20 minutes, and at the end of that time only suffered a slight headache, although later he became ill. The illness lasted several hours and was accompanied by nausea and headache.

The experiment shows that small birds are much more susceptible to the action of carbon monoxide than are men, and demonstrates the desirability of using small birds, such as canaries, rather than larger ones, such as pigeons.

In company with other persons the author has also witnessed practical demonstrations of the usefulness of canary birds in exploring mines after explosions had occurred therein. The following analysis shows the composition of the air about 200 feet beyond the point at which a canary bird collapsed. The bird was carried by an exploring party without breathing apparatus. A miner's lamp would burn in this atmosphere, which is typical of those that have caused many deaths in rescue parties, and would give no warning of the presence of the deadly white damp.

Composition of a mine atmosphere rendered dangerous by white damp.

Analysis of atmosphere.		Analysis differently stated.		
CO_2	1.49	Air	Oxygen	18.25
O_2	18.25		Nitrogen	69.07
CO	.60		Carbon dioxide	.03
CH_4	1.25	Black damp	Nitrogen	9.05
H_2	.29		Carbon dioxide	1.46
N_2	78.12	Methane		1.25
		White damp		.60
		Hydrogen		.29
	100.00			100.00

Generated on 2024-09-28 11:06 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

A sample of the atmosphere was not obtained at the exact place where the bird collapsed, but was taken at the face of a heading 200 feet beyond and close to what was supposed to have been the seat of the explosion. The exploring party was cautiously advancing along the heading when the bird collapsed; the members of the party immediately retreated without themselves feeling any distress. The bird quickly revived when placed in better air. About one hour later a helmeted party advanced to the face of the heading and collected the sample of air mentioned. The sample was obtained 18 hours after the explosion and before ventilation had been restored in this part of the heading. The carbon monoxide content of the air at the place where the bird collapsed is problematical, but certainly was less than 0.60 per cent, because the air was purer at places in the heading farther back from the face. As a rough guess, the carbon monoxide content may be placed at 0.20 or 0.30 per cent.

The following analysis shows the composition of the atmosphere in an entry that had been more or less traversed by exploring parties for several hours prior to the taking of the sample:

Composition of atmosphere in an entry traversed by exploring parties.

CO_2	0.31
O_2	20.51
CO	.04
CH_4	.20
H_2	.00
N_2	78.94
	100.00

One member complained of not feeling well at the time the sample was collected, but in prior exploration work he had probably breathed for several hours air containing small proportions of carbon monoxide. Hence, his symptoms were to be attributed to the cumulative effect of the air previously breathed rather than to the immediate action of the small proportion of carbon monoxide shown in the sample.

Another advantage of the use of birds in exploring mines remains to be considered. A mine atmosphere may be so deficient in oxygen as to extinguish a lamp flame and yet may not contain so little oxygen, or so much carbon monoxide, as to cause distress to birds. In exploring a mine after an explosion a party including members of the Bureau of Mines encountered an atmosphere that, as shown by analysis of a sample, contained the following gases:

Composition of an afterdamp.

CO_2	4.10
O_2	13.64
CO	.00
H_2	.00
CH_4	1.20
N_2	81.06
	100.00

Generated on 2024-09-28 10:55 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

The party was not equipped with breathing apparatus but carried safety lamps and birds. When it entered this atmosphere the lamps were extinguished (an oil lamp goes out in air containing less than 17 per cent oxygen), but neither the men nor the birds showed signs of distress.

In regard to the oxygen deficiency required to cause distress in men, Haldane [a] says:

When the oxygen percentage of air is gradually reduced by absorption of the oxygen, or (what is exactly the same thing) by addition of nitrogen, very little may be felt before the occurrence of impairment of the senses and loss of power over the limbs. If reduction is gradual, and the symptoms be carefully watched, it will be noticed that at about 12 per cent of oxygen, i. e. with a reduction of 9 per cent, the respirations become just perceptibly deeper. At 10 per cent the respirations are distinctly deeper and more frequent, and the lips become slightly bluish. At 8 per cent the face begins to assume a leaden color, though the distress is still not great. With 5 or 6 per cent there is marked panting, and this is accompanied by clouding of the senses and loss of power over the limbs, which would probably end sooner or later in death. It is probable that any sudden exertion made in air markedly deficient in oxygen may lead to temporary loss of consciousness, so that sudden efforts should be avoided in all cases where, through accident or necessity, a man is in an atmosphere which will not support light, and in such a position that he might fall into worse air or otherwise injure himself. When air containing less than 1 or 2 per cent of oxygen is breathed, loss of consciousness, without any distinct warning symptoms, occurs within 40 or 50 seconds. Loss of consciousness in air deprived of oxygen is more rapid than in drowning or strangling, since in the former case not only is the supply of fresh oxygen cut off, but the oxygen previously in the lungs is rapidly washed out. Loss of consciousness is quickly succeeded by convulsions, which are followed by cessation of the respirations. The heart still continues to beat, in the case of cats and dogs, for from two to eight minutes; in man this period is probably longer, for it seems to be the general rule that the larger an animal is the longer it will resist asphyxiation. So long as the heart is beating, however feebly, animation may be restored by artificial respiration. This may require to be continued for a considerable period, as the after effects of deprivation of oxygen are very serious, and the respiratory center may not recover for some time.

The above statement shows why the atmosphere previously mentioned put out the lamps, but did not affect the men, and seemingly had little effect upon the birds. Of course men not wearing breathing apparatus should retreat at once from an atmosphere that extinguishes an oil-lamp flame and thus avoid the possibility of suddenly entering an atmosphere so deficient in oxygen that safe retreat would be difficult. For although birds would undoubtedly indicate in season a deficiency of oxygen sufficient to cause distress to men, if further advance were made, yet immediate retreat from an atmosphere in which a lamp does not burn assures a larger margin of safety.

---

[a] Haldane, J. S., The causes of deaths in colliery explosions and underground fires. Report to the Secretary of State for the Home Department, 1896, p. 15.

Generated on 2024-09-28 11:00 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

CONCLUSION.

In bringing these tests to the attention of miners and mine officials the author makes no claim to originality in the use of birds or mice for the purpose of detecting harmful quantities of carbon monoxide in the air of a mine. Dr. Haldane strongly recommends their use. In this country, however, small animals have been used for the purpose described in comparatively few cases. For that reason and because the test is so simple and practical the author has added his observations to the work of Dr. Haldane in order to urge the general adoption of the test in this country. The fact that no series of tests of the comparative merits of birds and mice in atmospheres containing the entire range of small quantities of carbon monoxide had been made is a sufficient reason for the experiments described in the preceding pages. Further, the author's observations indicate that mice are hardly as sensitive to carbon monoxide poisoning as Dr. Haldane's experiments would indicate, and that small birds are better indicators of poisonous atmospheres than are mice.

PUBLICATIONS ON MINE ACCIDENTS AND EXPLOSIVES.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETINS.

BULLETIN 17. A primer on explosives for coal miners, by Charles E. Munroe and Clarence Hall. 69 pp. 10 pls. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by George S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp. 14 pls. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 26. Notes on explosive mine gases and dusts, with special reference to explosions in the Monongah, Darr, and Naomi coal mines, by R. T. Chamberlin. 67 pp. Reprint of United States Geological Survey Bulletin 383.

MINERS' CIRCULARS.

MINERS' CIRCULAR 2. Permissible explosives tested prior to January 1, 1911, and precautions to be taken in their use, by Clarence Hall. 1911. 12 pp.

MINERS' CIRCULAR 3. Coal-dust explosions, by George S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp.

MINERS' CIRCULAR 5. Electrical accidents in mines, their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp.

TECHNICAL PAPERS.

TECHNICAL PAPER 4. The electrical section of the Bureau of Mines, its purpose and equipment, by H. H. Clark. 1911. 13 pp.

TECHNICAL PAPER 6. The rate of burning of fuse, as influenced by temperature and pressure, by W. O. Snelling, 1911. 28 pp.

TECHNICAL PAPER 7. Investigations of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1911. 19 pp.

Generated on 2024-09-28 11:06 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

Technical Paper 11a. (2d ed.) For 3d ed. see next paper.

SEP 23 1912
PRINCETON, N. J.

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

THE USE OF MICE AND BIRDS FOR DETECTING CARBON MONOXIDE AFTER MINE FIRES AND EXPLOSIONS

BY

GEORGE A. BURRELL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1912

Generated on 2024-09-28 10:56 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

Digitized by Google

Original from
PRINCETON UNIVERSITY

CONTENTS.

	Page.
Introduction	3
Occurrence of carbon monoxide	5
Properties of carbon monoxide	6
Physiological effect of carbon monoxide	6
Chemical tests for carbon monoxide	8
The use of mice and birds	8
Experiments with mice	8
Experiments with birds	11
Summary	12
Relative susceptibility of men and birds	12
Conclusion	15
Publications on mine accidents and tests of explosives	16

Second edition, revised. July, 1912.
First edition issued in April, 1912.

Generated on 2024-09-28 11:02 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

THE USE OF MICE AND BIRDS FOR DETECTING CARBON MONOXIDE AFTER MINE FIRES AND EXPLOSIONS.

By GEORGE A. BURRELL.

INTRODUCTION.

In connection with its investigation of the causes of mine fires and explosions the Bureau of Mines is making a careful study of the methods that can be used with greatest efficiency for exploring mines containing smoke or suffocating or poisonous gases.

The presence of that poisonous gas, carbon monoxide (white damp), in the afterdamp of explosions and fires in mines has caused the death of a great many miners. An inspection of the reports of those explosions and mine fires in which men have been killed shows that this gas is often the cause of the majority of the fatalities. Haldane [a] makes the statement that carbon-monoxide poisoning is responsible for nearly all the fatalities. After a recent disaster at a mine in Pennsylvania in which 21 men were killed the bodies of 17 men showed no such marks of violence as would be produced by the concussion of an explosion. Tests of blood from some of these bodies clearly showed the bright pink hue caused by carbon monoxide. Examination of the blood of victims of other explosions has shown that carbon monoxide was largely responsible for the fatalities. Not only have men present in mines at the time of disasters succumbed to this gas, but rescuers endeavoring to save their unfortunate comrades have perished also.

Of the gases produced in mines, carbon monoxide is the most feared and the most difficult to detect. A miner's lamp gives warning of almost every dangerous condition of the atmosphere in a mine except the presence of this gas. Percentages of methane below those that form explosive mixtures can be detected by the appearance of the "cap" of the lamp flame, and a deficiency of oxygen is shown by the smothering of the flame in time for a retreat to be made before bodily harm can result. Carbon monoxide, however, may be present in deadly quantities in an atmosphere without the safety lamp detecting it, because a proportion much below that required to give a cap on a lamp flame is extremely poisonous.

Other gases occasionally found in mines in harmful quantity, such as hydrogen sulphide, and oxide of nitrogen fumes can be detected

[a] Foster, C. LeN., and Haldane, J. S. The investigation of mine air. 1905. P. 144.

Generated on 2024-09-28 11:01 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

even in great dilution by their odor, so that fatalities from the presence of these gases in mines are few.

The author tested the value of a wick flame as a detector of carbon monoxide in comparison with its value as a detector of methane. A Wolfe safety lamp, constructed so that prepared mixtures of air and carbon monoxide could be fed into it at the base, was used. The minimum percentage of carbon monoxide (about 2 per cent) required to produce a visible cap was found to be almost identical with the required proportion of methane. Two observers could detect no difference in the color or the height of the caps produced by this percentage of either gas. Neither could they when 3 per cent of either gas was used.

In a mine some observers, especially after becoming accustomed to the darkness ("getting eyesight," as it is termed), may detect a cap when the air contains less than 2 per cent of methane, and it is possible to detect less than 2 per cent of methane by the use of special testing lamps. But the point brought out by the author's experiments is that low percentages of either methane or carbon monoxide scarcely give caps that distinguish one gas from the other. Moreover, it has been the author's experience that when a given percentage of carbon monoxide is present in the air of a coal mine, a larger percentage of methane is usually present, so that this gas would interfere with the detection of carbon monoxide by a lamp even if carbon monoxide enough to give by itself a characteristic cap were present. It is also true that in the afterdamp of mines carbon monoxide in quantity sufficient to produce a cap usually accompanies a deficiency of oxygen and an excess of nitrogen, so that the lamp is extinguished before it can show a cap. One result of this last fact, however, is that the indications of a lamp may sometimes prevent a man from going into an atmosphere containing carbon monoxide enough to be rapidly poisonous.

The gases that come out of the crevices in the coal bed immediately after shots of explosives may contain much carbon monoxide and hydrogen, besides methane, and when a lamp is held close to the crevices the carbon monoxide and hydrogen may cause the cap of the lamp flame to differ somewhat from the cap produced by methane alone. In exploring mines, however, the great danger to a rescue party is from small proportions of carbon monoxide—proportions so small that they have no visible effect upon the flame.

The author is aware that some mining men are of the opinion that a percentage of carbon monoxide below that which is immediately dangerous perceptibly brightens or lengthens the flame of a lamp, but he knows of no characteristic of carbon monoxide that would warrant such an opinion. A possible explanation of the brightening or lengthening, suggested by J. W. Paul, mining engineer of this

Generated on 2024-09-28 11:05 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

bureau, lies in the fact that a party exploring a mine containing afterdamp sometimes enters a place in which the proportion of oxygen in the air is larger than it was in the place previously explored, and as a consequence the wick flame burns for a while with increased intensity. As the oxygen content of an atmosphere decreases, the flame of an oil lamp burns more dimly until, at 17 or 17.5 per cent of oxygen, the flame is extinguished.

OCCURRENCE OF CARBON MONOXIDE.

Carbon monoxide has not been positively identified in the samples of what may be termed normal mine air collected by this bureau, except in samples collected at the working faces where the air was vitiated by powder smoke. Samples of mine air from the ventilating current, from the main returns, and from splits have been examined, also samples from inclosed areas in which the air had been still; but although the apparatus used was accurate to 0.02 per cent, the author can not state positively that carbon monoxide was present in any of the samples. A series of tests is now being conducted in which air from sealed bottles containing coal that was freshly mined at the time of bottling is being examined for minute quantities of combustible gases other than methane. Although about 12 examinations have been made of samples taken one week apart, the presence of carbon monoxide has not been positively determined.

It appears that carbon monoxide is produced in mines in harmful quantity only through the agency of heat or by the incomplete combustion of carbon that attends explosions, mine fires, the use of explosives, etc. The gas is produced by the imperfect combustion and dry distillation of coal dust in explosions, by the imperfect combustion of methane, by the burning of wood and coal with insufficient supply of oxygen, and by the contact of previously formed carbon dioxide with red-hot carbon, as when the flame of a blast or a gas explosion is projected into an atmosphere filled with the fine coal dust. The last-named cause operates toward the formation of carbon monoxide when those explosives that contain within themselves sufficient oxygen for the complete oxidization of their carbonaceous components are used in breaking down coal.

The carbon monoxide formed, with hydrogen and methane, collects in the open spaces and crevices behind a standing shot, and the miner is often burned by the flame that bursts forth when he carelessly puts his lamp close to a crevice or into an open space to examine the effect of a blast. Besides the danger that attends the burning of these crevice gases, trouble is often experienced from the gases that result from the use of improperly handled explosives in ill-ventilated parts of a mine. A series of experiments is being carried on by the Bureau of Mines to determine the gases that are produced by the firing of

Generated on 2024-09-28 11:00 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

different explosives and the extent to which the use of the explosive vitiates the air of the working places.

PROPERTIES OF CARBON MONOXIDE.

Carbon monoxide is a colorless and inodorous gas with a specific gravity of 0.967. A liter of it weighs 1.2506 grams at 0° C. and 760 mm. pressure.[a] It will not support combustion, but burns with a pale blue flame. The lambent flame above a grate in which anthracite or coke is burning is due to the combustion of this gas. Carbon monoxide is the main combustible ingredient of water gas, of producer gas, and of blast-furnace gas, which contain approximately 15 to 40 per cent of it, and is present, but in smaller proportion, in illuminating gas made by the destructive distillation of coal. It has not been identified as a constituent of the samples of natural gas examined by the Bureau of Mines, a fact that accounts for natural gas being less poisonous than water gas, producer gas, or ordinary illuminating gas. Carbon monoxide in mixtures with air has a wide range of explosibility, from 16.5 per cent gas, lower limit, to 74.95 per cent gas, higher limit.[b] Methane has explosive limits that lie between about 6.1 per cent gas, lower limit, and 12.8 per cent gas, higher limit.[c] The lower limits cited have reference to complete combustion and to the ignition of the gas by an electric spark. Other modes of ignition, changes in temperature, the shape of the containing vessel, differences in pressure, and the presence of more or less water vapor may change the range of explosibility somewhat. The addition of a large quantity of carbon monoxide to explosive mixtures of methane and air would have the tendency to widen the upper limit of explosibility over that of methane alone. The author has found that the addition of as little as 2.2 per cent of carbon monoxide to a mixture of methane and air in which the proportion of methane was about 1 per cent under the explosive proportion made the mixture explosive. This fact is of importance from its bearing on the explosiveness of mine atmospheres during mine fires or after an explosion.

PHYSIOLOGICAL EFFECT OF CARBON MONOXIDE.

The oxygen absorbed from the air in the lungs is normally taken up by the blood in the form of a loose chemical combination with the red coloring matter (hæmoglobin) of the corpuscles, and in this form it is carried to the tissues where it is used. Hæmoglobin not only combines with oxygen but also forms a far more stable compound with carbon monoxide and when saturated with the latter it can not take up oxygen. Hence, when the corpuscles in the blood of a living animal are saturated with carbon monoxide they can not carry oxygen from the lungs to the tissues, and death must result. According to Haldane,[d] carbon monoxide has no other effect than that resulting from its interference with the oxygen supply of the tissues, and apart

[a] Rayleigh. Proc. Royal Soc. London. Vol. 62, 1897, p. 204.
[b] Jour. Soc. Chem. Ind. Vol. 21, 1902, p. 395.
[c] Idem.
[d] Jour. Physiology. Vol. 18, 1895, pp. 200, 430, 463.

Generated on 2024-09-28 11:06 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

from its property of combining with hæmoglobin it is physiologically indifferent, like nitrogen.

The affinity of carbon monoxide for hæmoglobin is about 250 [a] times as great as the affinity of the latter for oxygen. However, if oxygen is administered to a person not too far overcome the carbon monoxide will be completely driven out of the blood. In this respect pure oxygen acts about five times as rapidly as normal air, which contains approximately 21 per cent of oxygen. From air containing very small percentages of carbon monoxide, less than 0.1 per cent, the blood of a man does not take up enough of the gas to cause distress unless the man breathes such air a long time. If the air contains larger proportions, the blood sooner or later reaches that stage of partial saturation with carbon monoxide that produces helplessness. Haldane [b] makes the following observation:

> The blood of a man will take up about two pints of CO or oxygen. A man at rest breathes about 10 or 12 pints of air per minute, and experiment shows that of the carbon monoxide inhaled about 60 per cent is absorbed by the blood. If a man would breath air containing 0.1 per cent of carbon monoxide he would absorb 0.007 pint per minute. It would then take him nearly 2.25 hours to absorb a whole pint or produce one-half saturation of the blood, at which stage the limbs would become so weak as to cause them to give way when an effort was made to walk. A man who is walking, however, breathes about three times as much air as a man who is at rest, hence he might absorb a pint within an hour. With 0.2 per cent of carbon monoxide the time would be one-half as long, with 0.3 per cent, one-third as long, etc.

If a man who has breathed mine air containing carbon monoxide and has retired to fresh air to recuperate, again enters workings containing this gas before the carbon monoxide has entirely been displaced from his blood, he feels the effects of the gas in less time than when he entered the workings before.

The experience of those who have been partly poisoned by carbon monoxide seems to teach that usually much pain or distress does not precede collapse. One of the first symptoms is weakness of the limbs and dimness of eyesight. For some time after resuscitation, however, there may be severe headache, or even epileptic seizures and other serious ailments.

Poisoning by carbon monoxide can take place very suddenly. For instance, a man in a mine may quickly pass from a place containing such a small quantity of the gas that he has experienced no distress into a place containing a larger quantity where, because of the already partially saturated condition of the blood, he will quickly succumb. Also, the action of the poison may be accelerated by increased exertion, such as climbing a steep incline or ladder, or lifting heavy weights.

---

[a] Haldane, J. S., Causes of death in colliery explosions and underground fires. Report to the Secretary of State for the Home Department. 1896.

[b] Idem, p. 17.

Generated on 2024-09-28 10:58 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

CHEMICAL TESTS FOR CARBON MONOXIDE.

The author has by the aid of a portable gas-analysis apparatus made tests of the air in mines after explosions and fires and has thus ascertained on the spot the composition of the atmosphere in the workings. Because of the time required to make such tests and the need of the services of a person with some knowledge of gas-analysis apparatus, chemical tests of the atmosphere in a mine immediately after a disaster are not made as often as they should be. Another reason for omitting them is that quick chemical tests for small quantities of carbon monoxide are not made as successfully as are chemical tests for methane, carbon dioxide, and oxygen.

Perhaps the best chemical test for carbon monoxide, in that other gases do not interfere and very simple apparatus is required, is by the use of blood diluted with water to a buff-yellow tint. This test, in the author's experience, is capable of distinctly showing as little as 0.03 per cent of carbon monoxide in the atmosphere. The method of procedure is as follows:

One or two drops of blood drawn from the finger are diluted with water until equal portions of the solution placed in 100 c. c. test tubes have a buff-yellow color. One of the tubes is taken into the mine, and at the place where the air is to be tested about 50 c. c. of the blood solution is poured out, the mine air taking its place. The tube is then corked, taken to the surface, and gently shaken for 10 minutes. If the air contained carbon monoxide the pink color caused by the presence of carbon monoxide hæmoglobin is detected by comparing the solution with the normal blood solution in the other tube.

A fresh active solution of cuprous chloride may be used instead of blood for examining air for carbon monoxide. According to the author's experience, the use of such a solution, if the apparatus is precise and is properly manipulated, will show proportions of carbon monoxide harmful to a rescue party.

THE USE OF MICE AND BIRDS.

EXPERIMENTS WITH MICE.

In the author's opinion the use of birds and mice is superior to chemical tests for carbon monoxide in that the test is quickly made, requires no technical experience, and is sufficiently exact.

Two or three mice or small birds can be placed in a cage and carried into the mine with an exploring party. Because the rate at which chemical changes occur in them is enormously greater than it is in a man, they show symptoms of poisoning far sooner. Haldane [a] states that a mouse weighing one-half an ounce consumes about 15 times as much oxygen as one-half ounce of the human body would consume in

[a] Colliery Guardian, vol. 98, Dec. 17, 1909, p. 1251.

Generated on 2024-09-28 10:56 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

the same time. With 0.1 per cent of carbon monoxide in the air, Haldane found that about two hours elapsed before giddiness, etc., began to appear in a man at rest, and, according to an analysis of the blood, exposure for another half hour would have sufficed to produce practical disablement. A mouse became giddy in 10 minutes. With 0.6 per cent of carbon monoxide in the air, all of the animals tried became helpless in two minutes and rapidly became comatose or died, whereas a person breathing the mixture was entirely unaffected even after 10 minutes. An examination of this person's blood showed that it was one-fourth saturated.

In experiments at the laboratory of the Pittsburgh station of the Bureau of Mines white mice were placed in air containing the following percentages of carbon monoxide: 0.16 per cent, 0.2 per cent, 0.33 per cent, 0.46 per cent, 0.37 per cent, and 0.77 per cent. The mice were placed under a tight glass bell jar having a capacity of 10 liters, into which carbon monoxide had previously been introduced. The atmosphere inside the jar was thoroughly mixed and sampled twice during the experiment, the samples being taken from different points in order to make sure that the content of carbon monoxide was uniformly distributed. The samples were analyzed by combustion of the carbon monoxide in an apparatus with which duplicate analyses agreeing within 0.01 per cent could be performed.

An analysis of the air in the jar at the end of one hour showed that the oxygen content had been depleted 1 per cent, due to the breathing of the mouse, or not enough to affect the latter. In air containing 0.16 per cent of carbon monoxide, a mouse showed signs of sluggishness in about six minutes, but this sluggishness, judged by outward manifestations, did not increase to any great extent up to the time the mouse was taken from the jar two hours later. The animal's rate of breathing had dropped from a normal of 160 respirations to about 120 respirations per minute. The mouse did not evince such signs of distress as would serve, if the mouse were carried into an atmosphere containing carbon monoxide, to indicate in one hour's time the presence of 0.1 per cent of the gas.

In air containing 0.2 per cent of carbon monoxide a mouse suffered partial collapse in 15 minutes and showed decided symptoms of distress in eight minutes. At the end of an hour it had not lost all muscular power. It died in two hours.

In air containing 0.31 per cent of carbon monoxide a mouse suffered partial collapse in seven and one-half minutes and showed decided symptoms in about four minutes; but 35 minutes had elapsed before it lost all muscular power and ability to turn over when placed on its back. After removal from the bell jar, the mouse was seemingly in normal condition again in about two hours.

In air containing 0.46 per cent of carbon monoxide a mouse gave decided signs of distress in two minutes; staggered around and showed

Generated on 2024-09-28 11:03 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

partial collapse in four minutes; and in six minutes had lost all muscular power.

In air containing 0.57 per cent of carbon monoxide a mouse showed decided symptoms of distress in one minute, partly collapsed in two minutes, lost all muscular power in seven minutes, and died in 16 minutes.

In air containing 0.77 per cent of carbon monoxide a mouse showed distinct signs of distress in one minute. It lost all muscular power in five and one-half minutes and died in 12½ minutes.

The experiments showed that in air containing the smaller percentages of carbon monoxide the mice displayed varying degrees of activity up to the time they exhibited pronounced distress. Of course, the value of the tests in exploring mines depends upon the warning that the mice give while they are being affected by the carbon monoxide, and it is especially desirable that their actions should indicate the presence of extremely small proportions of carbon monoxide, so that men will have ample time to retire from an atmosphere that contains such proportions of the gas. In the experiments it was found that in small quantities of gas and under like conditions, one mouse might clearly exhibit signs of distress whereas another might become comatose without showing distress so distinctly. Consequently, in using the test, the mouse should be closely watched, and a man not wearing breathing apparatus should retire at once from any part of a mine where the atmosphere distresses a mouse. It is advisable to carry at least three mice at a time into a mine, and to prod them slightly if they remain too quiet, in order to observe them in action.

A man, when he exerts himself by carrying heavy objects, climbing ladders, or running, consumes in a given time more oxygen and also more carbon monoxide than when he rests. Consequently, a man at work might feel symptoms of carbon-monoxide poisoning that would not be clearly shown by a mouse confined in a cage in the same atmosphere. In an atmosphere containing the small quantities of carbon monoxide usually found in mines after explosions and mine fires, a person may be able to go a long distance without experiencing much inconvenience. On the return trip, however, the symptoms may become so aggravated that considerable difficulty may be experienced in getting to the base of operations or to the surface.

The composition of the atmosphere in the experimental mine of the bureau, 15 minutes after an explosion of coal dust, is shown by the following analysis of a sample collected about 200 feet from the mouth of the main entry:

Generated on 2024-09-28 10:56 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

Composition of the atmosphere in the experimental mine after a dust explosion.

CO_2	1.47
O_2	18.30
CO	1.08
H_2	.35
CH_4	.16
N_2	78.64
	100.00

The noxious properties of this atmosphere are due to the carbon monoxide. The author prepared an atmosphere of similar composition and found that a mouse placed in it lost all power of movement in 4½ minutes.

EXPERIMENTS WITH BIRDS.

Because mice may be slow in responding to the presence, in the mine air, of such small percentages of carbon monoxide as would cause distress to a man at work, experiments similar to those performed with mice were tried with birds. Canaries were confined in a bell jar in atmospheres containing the following percentages of carbon monoxide: 0.09 per cent, 0.12 per cent, 0.15 per cent, 0.2 per cent, and 0.29 per cent.

After an exposure of one hour to an atmosphere containing 0.09 per cent of carbon monoxide, a bird was not affected to such an extent that it would, if carried into a mine, indicate by its actions the presence of that proportion of carbon monoxide. Only by close observation could one detect that the bird at the end of an hour felt slightly distressed.

With 0.12 per cent of carbon monoxide in the atmosphere of the bell jar, a bird did not show clearly symptoms of being affected. In about 15 minutes it had lost its liveliness and thenceforth remained comparatively quiet. The bird did not fall from the perch, but close observation showed that it was decidedly weaker at the end of the hour than was the bird placed in air containing 0.09 per cent of carbon monoxide.

In air containing 0.15 per cent of carbon monoxide, a bird evinced symptoms of slight distress in three minutes. It gasped, gradually became weaker, swayed, and at the end of 18 minutes fluttered from the perch. At the end of an hour it had not lost all muscular power, but showed symptoms of extreme weakness.

In air containing 0.2 per cent of carbon monoxide, a bird showed pronounced signs of distress in one and one-half minutes; it became very unsteady in three minutes, and fell from the perch in five minutes. After it was taken from the jar it regained its feet in two minutes and appeared to be in normal condition in five minutes.

In air containing 0.29 per cent of carbon monoxide, a bird fell from the perch in two and one-half minutes. When placed in fresh air again it almost revived in five minutes.

Generated on 2024-09-28 10:58 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

SUMMARY.

The following table shows the relative susceptibilities of mice and canaries to carbon-monoxide poisoning:

Effect of CO on mice and canaries.

Mice.		Canaries.	
Per cent CO.	Effect.	Per cent CO.	Effect.
0.16	Very slight distress at end of hour.....	0.09	Very slight distress at end of hour.
.20	Distress in 8 minutes; partial collapse in 15 minutes.	.12	Weaker at end of hour than after exposure to 0.9 per cent.
.31	Distress in 4 minutes; collapse in 7½ minutes; lost muscular power in 35 minutes.	.15	Distress in 3 minutes; fell from perch in 18 minutes.
.46	Distress in 2 minutes; collapse in 4 minutes.	.20	Distress in 1½ minutes; fell from perch in 5 minutes.
.57	Distress in 1 minute; collapse in 2 minutes; muscular power lost in 7 minutes; death in 16 minutes.	.29	Fell from perch in 2½ minutes.
.77	Distress in 1 minute; muscular power lost in 6½ minutes; death in 12½ minutes.	.....	

These tests show that canaries may be better than mice as indicators of the presence of noxious gases in the atmosphere of mines, since they more quickly show signs of distress in the presence of small quantities of carbon monoxide. In addition the symptoms of poisoning in birds are much more clearly defined. A bird sways noticeably on its perch before falling and its fall is a better indication of danger than is the squatting, extended posture that some mice assume without much struggling, attempts to walk, or other preliminary symptom of poisoning. Consequently birds not only give more timely warning of the presence of small quantities of carbon monoxide, but exhibit symptoms that are more easily noticed by exploring parties.

RELATIVE SUSCEPTIBILITY OF MEN AND BIRDS.

In order to determine for himself the relative susceptibility of men and birds to the action of carbon monoxide, the author performed the following experiment:

A gas-tight chamber, having a capacity of 80 cubic feet, was constructed. Into this chamber sufficient carbon monoxide was introduced to produce an atmosphere containing 0.25 per cent of the latter. The author entered this atmosphere, taking with him canary birds and pigeons. The canaries evinced distress in one minute and fell from their perches in three minutes. The pigeons showed only slight distress in 11 minutes. The author remained in the atmosphere for 20 minutes; he then had a slight headache, but later was ill 10 hours and suffered nausea and severe headache. Remaining in the atmosphere for 20 minutes more would have caused complete collapse and serious after effects.

Generated on 2024-09-28 11:00 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

The experiment shows that small birds are much more susceptible to the action of carbon monoxide than are men, and demonstrates the desirability of using small birds, such as canaries, rather than larger ones, such as pigeons.

It has been demonstrated that men differ greatly in susceptibility to carbon-monoxide poisoning.

In company with other persons the author has witnessed several practical demonstrations of the usefulness of canary birds in exploring mines after explosions had occurred therein. The following analysis shows the composition of the air about 200 feet beyond the point at which a canary bird collapsed. The bird was carried by an exploring party without breathing apparatus. A miner's lamp would burn in this atmosphere, which is typical of those that have caused many deaths in rescue parties, and would give no warning of the presence of the deadly white damp.

Composition of a mine atmosphere rendered dangerous by white damp.

Analysis of atmosphere.		Analysis differently stated.	
CO_2	1.49	Air: Oxygen	18.25
O_2	18.25	Air: Nitrogen	69.07
CO	.60	Air: Carbon dioxide	.03
CH_4	1.25	Black damp: Nitrogen	9.05
H_2	.29	Black damp: Carbon dioxide	1.46
N_2	78.12	Methane	1.25
		White damp	.60
	100.00	Hydrogen	.29
			100.00

A sample of the atmosphere was not obtained at the exact place where the bird collapsed, but was taken at the face of a heading 200 feet beyond and close to what was supposed to have been the seat of the explosion. The exploring party was cautiously advancing along the heading when the bird collapsed; the members of the party immediately retreated without themselves feeling any distress. The bird quickly revived when placed in better air. About one hour later a helmeted party advanced to the face of the heading and collected the sample of air mentioned. The sample was obtained 18 hours after the explosion and before ventilation had been restored in this part of the heading. The carbon monoxide content of the air at the place where the bird collapsed is problematical, but certainly was less than 0.60 per cent, because the air was purer at places in the heading farther back from the face. As a rough guess, the carbon monoxide content may be placed at 0.20 or 0.30 per cent.

Generated on 2024-09-28 10:57 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

The following analysis shows the composition of the atmosphere in an entry that had been more or less traversed by exploring parties for several hours prior to the taking of the sample:

Composition of atmosphere in an entry traversed by exploring parties.

CO_2	0.31
O_2	20.51
CO	.04
CH_4	.20
H_2	.00
N_2	78.94
	100.00

One member complained of not feeling well at the time the sample was collected, but in prior exploration work he had probably breathed for several hours air containing small proportions of carbon monoxide. Hence, his symptoms were to be attributed to the cumulative effect of the air previously breathed rather than to the immediate action of the small proportion of carbon monoxide shown in the sample.

Another feature of the use of birds in exploring mines remains to be considered. A mine atmosphere may be so deficient in oxygen as to extinguish a lamp flame and yet may not contain so little oxygen, or so much carbon monoxide, as to cause distress to birds. In exploring a mine after an explosion a party including members of the Bureau of Mines encountered an atmosphere that, as shown by analysis of a sample, contained the following gases:

Composition of an afterdamp.

CO_2	4.10
O_2	13.64
CO	.00
H_2	.00
CH_4	1.20
N_2	81.06
	100.00

The party was not equipped with breathing apparatus but carried safety lamps and birds. When the party entered this atmosphere the lamps were extinguished (an oil lamp goes out in air containing less than 17 per cent oxygen), but neither the men nor the birds showed signs of distress. The party immediately retreated.

In regard to the oxygen deficiency required to cause distress in men, Haldane[a] says:

> When the oxygen percentage of air is gradually reduced by absorption of the oxygen, or (what is exactly the same thing) by addition of nitrogen, very little may be felt before the occurrence of impairment of the senses and loss of power over the limbs.

[a] Haldane, J. S., The causes of deaths in colliery explosions and underground fires. Report to the Secretary of State for the Home Department, 1896, p. 15.

Generated on 2024-09-28 11:01 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

If reduction is gradual, and the symptoms be carefully watched, it will be noticed that at about 12 per cent of oxygen, i. e., with a reduction of 9 per cent, the respirations become just perceptibly deeper. At 10 per cent the respirations are distinctly deeper and more frequent, and the lips become slightly bluish. At 8 per cent the face begins to assume a leaden color, though the distress is still not great. With 5 or 6 per cent there is marked panting, and this is accompanied by clouding of the senses and loss of power over the limbs, which would probably end sooner or later in death. It is probable that any sudden exertion made in air markedly deficient in oxygen may lead to temporary loss of consciousness, so that sudden efforts should be avoided in all cases where, through accident or necessity, a man is in an atmosphere which will not support light, and in such a position that he might fall into worse air or otherwise injure himself. When air containing less than 1 or 2 per cent of oxygen is breathed, loss of consciousness, without any distinct warning symptoms, occurs within 40 or 50 seconds. Loss of consciousness in air deprived of oxygen is more rapid than in drowning or strangling, since in the former case not only is the supply of fresh oxygen cut off, but the oxygen previously in the lungs is rapidly washed out. Loss of consciousness is quickly succeeded by convulsions, which are followed by cessation of the respiration. The heart still continues to beat, in the case of cats and dogs, for from two to eight minutes; in man this period is probably longer, for it seems to be the general rule that the larger an animal is the longer it will resist asphyxiation. So long as the heart is beating, however feebly, animation may be restored by artificial respiration. This may require to be continued for a considerable period, as the after effects of deprivation of oxygen are very serious, and the respiratory center may not recover for some time.

The author has performed hard work for 20 minutes in an atmosphere containing 17 per cent of oxygen and 4 per cent of carbon dioxide; he suffered little discomfort other than a deepening of the breathing and a slight headache. The air was kept in motion by a fan; stopping the fan increased the feeling of discomfort.

Haldane's statement shows why the atmosphere previously mentioned put out the lamps, but did not affect the men, and seemingly had little effect upon the birds. Of course, men not wearing breathing apparatus should retreat at once from an atmosphere that extinguishes an oil-lamp flame and thus avoid the possibility of suddenly entering an atmosphere so deficient in oxygen that safe retreat would be difficult. For although birds would undoubtedly indicate in season a deficiency of oxygen sufficient to cause distress to men, if further advance were made, yet immediate retreat from an atmosphere in which a lamp does not burn assures a larger margin of safety.

The use of birds should accompany the use of breathing helmets, so that where the air is good, as indicated by the birds, the men can save the supply of oxygen in their apparatus.

CONCLUSION.

In bringing these tests to the attention of miners and mine officials the author makes no claim to originality in the use of birds or mice for the purpose of detecting harmful quantities of carbon monoxide in the air of a mine. Dr. Haldane strongly recommends their use. In this country, however, small animals have been used for the pur-

Generated on 2024-09-28 11:03 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

pose described in comparatively few cases. For that reason and because the test is so simple and practical the author has added his observations to the work of Dr. Haldane in order to urge the general adoption of the test in this country. The fact that no series of tests of the comparative merits of birds and mice in atmospheres containing the entire range of small quantities of carbon monoxide had been made is a sufficient reason for the experiments described in the preceding pages. Further, the author's observations indicate that mice are hardly as sensitive to carbon monoxide poisoning as Dr. Haldane's experiments would indicate, and that small birds are better indicators of poisonous atmospheres than are mice.[a]

PUBLICATIONS ON MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

The following Bureau of Mines publications may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C.:

BULLETINS.

BULLETIN 17. A primer on explosives for coal miners, by Charles E. Munroe and Clarence Hall. 69 pp. 10 pls. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by George S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp. 14 pls. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 26. Notes on explosive mine gases and dusts, with special reference to explosions in the Monongah, Darr, and Naomi coal mines, by R. T. Chamberlin. 67 pp. Reprint of United States Geological Survey Bulletin 383.

MINERS' CIRCULARS.

MINERS' CIRCULAR 2. Permissible explosives tested prior to January 1, 1911, and precautions to be taken in their use, by Clarence Hall. 1911. 12 pp.

MINERS' CIRCULAR 3. Coal-dust explosions, by George S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp.

MINERS' CIRCULAR 5. Electrical accidents in mines, their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp.

TECHNICAL PAPERS.

TECHNICAL PAPER 4. The electrical section of the Bureau of Mines, its purpose and equipment, by H. H. Clark. 1911. 13 pp.

TECHNICAL PAPER 6. The rate of burning of fuse, as influenced by temperature and pressure, by W. O. Snelling. 1911. 28 pp.

TECHNICAL PAPER 7. Investigations of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1911. 19 pp.

---

[a] The physiological effects of slight proportions, 0.05 per cent or less, of carbon monoxide in mine air will be discussed in a forthcoming report of the Bureau of Mines.

Generated on 2024-09-28 11:00 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

Technical Paper 11b. (3d ed.)

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

THE USE OF MICE AND BIRDS FOR DETECTING CARBON MONOXIDE AFTER MINE FIRES AND EXPLOSIONS

BY

GEORGE A. BURRELL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1914

Generated on 2024-09-28 11:01 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

CONTENTS.

	Page.
Introduction	3
Occurrence of carbon monoxide	5
Properties of carbon monoxide	6
Physiological effect of carbon monoxide	6
Chemical tests for carbon monoxide	8
The use of mice and birds	8
Experiments with mice	8
Experiments with birds	10
Summary	11
Relative susceptibility of men and birds	12
Conclusion	15
Publications on mine accidents and tests of explosives	15

Third edition, July, 1914.
First edition issued in April, 1912.

Generated on 2024-09-28 10:59 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google

Digitized by Google

Original from PRINCETON UNIVERSITY

THE USE OF MICE AND BIRDS FOR DETECTING CARBON MONOXIDE AFTER MINE FIRES AND EXPLOSIONS.

By GEORGE A. BURRELL.

INTRODUCTION.

In connection with its investigation of the causes of mine fires and explosions the Bureau of Mines is making a careful study of the methods that can be used with greatest efficiency for exploring mines containing smoke or suffocating or poisonous gases.

The presence of that poisonous gas, carbon monoxide (white damp), in the afterdamp of explosions and fires in mines has caused the death of a great many miners. An inspection of the reports of those explosions and mine fires in which men have been killed shows that this gas is often the cause of the majority of the fatalities. Haldane[a] makes the statement that carbon-monoxide poisoning is responsible for nearly all the fatalities. After a recent disaster at a mine in Pennsylvania in which 21 men were killed the bodies of 17 men showed no such marks of violence as would be produced by the concussion of an explosion. Tests of blood from some of these bodies clearly showed the bright pink hue caused by carbon monoxide. Not only have men present in mines at the time of disasters succumbed to this gas, but rescuers endeavoring to save their unfortunate comrades have perished also.

Of the gases produced in mines, carbon monoxide is the most feared and the most difficult to detect. A miner's lamp gives warning of almost every dangerous condition of the atmosphere in a mine except the presence of this gas. Percentages of methane below those that form explosive mixtures can be detected by the appearance of the "cap" of the lamp flame, and a deficiency of oxygen is shown by the smothering of the flame in time for a retreat to be made before bodily harm can result. Also, excessive proportions of carbon dioxide cause panting. Carbon monoxide, however, may be present in deadly quantities in an atmosphere without the safety lamp detecting it, because a proportion much below that required to give a cap on a lamp flame is extremely poisonous.

[a] Foster, C. LeN., and Haldane, J. S. The investigation of mine air. 1905. P. 144.

Generated on 2024-09-28 11:02 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

Other gases occasionally found in mines in harmful quantity, such as hydrogen sulphide, and oxide of nitrogen fumes can be detected even in great dilution by their odor, so that fatalities from the presence of these gases in mines are few.

The author tested the value of a wick flame as a detector of carbon monoxide in comparison with its value as a detector of methane. A Wolfe safety lamp, constructed so that prepared mixtures of air and carbon monoxide could be fed into it at the base, was used. The minimum percentage of carbon monoxide (about 2 per cent) required to produce a visible cap was found to be almost identical with the required proportion of methane. Two observers could detect no difference in the color or the height of the caps produced by this percentage of either gas. Neither could they when 3 per cent of either gas was used.

In a mine some observers, especially after becoming accustomed to the darkness ("getting eyesight," as it is termed), may detect a cap when the air contains less than 2 per cent of methane, and it is possible to detect less than 2 per cent of methane by the use of special testing lamps. But the point brought out by the author's experiments is that low percentages of either methane or carbon monoxide scarcely give caps that distinguish one gas from the other. Moreover, it has been the author's experience that when a given percentage of carbon monoxide is present in the air of a coal mine, a larger percentage of methane is usually present, so that this gas would interfere with the detection of carbon monoxide by a lamp even if carbon monoxide enough to give by itself a characteristic cap were present. It is also true that in the afterdamp of mines carbon monoxide in quantity sufficient to produce a cap usually accompanies a deficiency of oxygen and an excess of nitrogen, so that the lamp is extinguished before it can show a cap. One result of this last fact, however, is that the indications of a lamp may sometimes prevent a man from going into an atmosphere containing carbon monoxide enough to be rapidly poisonous.

The gases that come out of the crevices in the coal bed immediately after shots of explosives may contain much carbon monoxide and hydrogen, besides methane, and when a lamp is held close to the crevices the carbon monoxide and hydrogen may cause the cap of the lamp flame to differ somewhat from the cap produced by methane alone. In exploring mines, however, the great danger to a rescue party is from small proportions of carbon monoxide—proportions so small that they have no visible effect upon the flame.

The author is aware that some mining men are of the opinion that a percentage of carbon monoxide below that which is immediately dangerous perceptibly brightens or lengthens the flame of a lamp, but he knows of no characteristic of carbon monoxide that would warrant such an opinion. A possible explanation of the brightening

Generated on 2024-09-28 11:00 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

or lengthening, suggested by J. W. Paul, mining engineer of this bureau, lies in the fact that a party exploring a mine containing afterdamp sometimes enters a place in which the proportion of oxygen in the air is larger than it was in the place previously explored, and as a consequence the wick flame burns for a while with increased intensity. As the oxygen content of an atmosphere decreases, the flame of an oil lamp burns more dimly until, at 17 or 17.5 per cent of oxygen, the flame is extinguished.

OCCURRENCE OF CARBON MONOXIDE.

Carbon monoxide has not been positively identified in the samples of what may be termed normal mine air collected by this bureau, except in samples collected at the working faces where the air was vitiated by powder smoke. Samples of mine air from the ventilating current, from the main returns, and from splits have been examined, also samples from inclosed areas in which the air had been still; but although the apparatus used was accurate to 0.02 per cent, the author can not state positively that carbon monoxide was present in any of the samples. A series of tests is now being conducted in which air from sealed bottles containing coal that was freshly mined at the time of bottling is being examined for minute quantities of combustible gases other than methane. Although about 12 examinations have been made of samples taken one week apart, the presence of carbon monoxide has not been positively determined.

It appears that carbon monoxide is produced in mines in harmful quantity only through the agency of the heat and the incomplete combustion of carbon that attend explosions, mine fires, the use of explosives, etc. The gas is produced by the imperfect combustion and dry distillation of coal dust in explosions, by the imperfect combustion of methane, by the burning of wood and coal with insufficient supply of oxygen, and by the contact of previously formed carbon dioxide with red-hot carbon, as when the flame of a blast or a gas explosion is projected into an atmosphere filled with the fine coal dust. The last-named cause operates toward the formation of carbon monoxide when those explosives that contain within themselves sufficient oxygen for the complete oxidization of their carbonaceous components are used in breaking down coal.

The carbon monoxide formed, with hydrogen and methane, collects in the open spaces and crevices behind a standing shot, and the miner is often burned by the flame that bursts forth when he carelessly puts his lamp close to a crevice or into an open space to examine the effect of a blast. Besides the danger that attends the burning of these crevice gases, trouble is often experienced from the gases that result from the use of improperly handled explosives in ill-ventilated parts of a mine. A series of experiments is being carried on by the

Generated on 2024-09-28 11:00 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

Bureau of Mines to determine the gases that are produced by the firing of different explosives and the extent to which the use of the explosives vitiates the air of the working places.[a]

PROPERTIES OF CARBON MONOXIDE.

Carbon monoxide is a colorless and inodorous gas with a specific gravity of 0.967. A liter of it weighs 1.2506 grams at 0° C. and 760 mm. pressure.[b] It will not support combustion, but burns with a pale-blue flame. The lambent flame above a grate in which anthracite or coke is burning is due to the combustion of this gas. Carbon monoxide is the main combustible ingredient of water gas, of producer gas, and of blast furnace gas, which contain approximately 15 to 40 per cent of it, and is present, but in smaller proportion, in illuminating gas made by the destructive distillation of coal. It has not been identified as a constituent of the samples of natural gas examined by the Bureau of Mines, a fact that accounts for natural gas being less poisonous than water gas, producer gas, or ordinary illuminating gas. Carbon monoxide in mixtures with air, according to determinations by chemists of the Bureau of Mines, has a wide range of explosibility, from 15.5 per cent gas, lower limit, to 72 per cent gas, higher limit. Methane has explosive limits that lie between about 5.5 per cent gas, lower limit, and 13 per cent gas, higher limit. The lower limits cited have reference to complete combustion and to the ignition of the gas by an electric spark. Other modes of ignition, changes in temperature, the shape of the containing vessel, differences in pressure, and the presence of more or less water vapor may change the range of explosibility somewhat. The addition of a large quantity of carbon monoxide to explosive mixtures of methane and air would have the tendency to widen the upper limit of explosibility over that of methane alone.

PHYSIOLOGICAL EFFECT OF CARBON MONOXIDE.

The oxygen absorbed from the air in the lungs is normally taken up by the blood in the form of a loose chemical combination with the red coloring matter (hæmoglobin) of the corpuscles, and in this form it is carried to the tissues where it is used. Hæmoglobin not only combines with oxygen but also forms a far more stable compound with carbon monoxide and when saturated with the latter it can not take up oxygen. Hence, when the corpuscles in the blood of a living animal are saturated with carbon monoxide they can not carry oxygen from the lungs to the tissues, and death must result. According to Haldane,[c] carbon monoxide has no other effect than that resulting

[a] Hall, Clarence, and Howell, S. P., The selection of explosives used in engineering and mining operations: Bull. 48, Bureau of Mines. 1913. Pp. 10, 14, 20.

[b] Rayleigh. Proc. Royal Soc. London. Vol. 62, 1897, p. 204.

[c] Jour. Physiology. Vol. 18, 1895, pp. 200, 430, 463.

Generated on 2024-09-28 11:12 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

from its interference with the oxygen supply of the tissues, and apart from its property of combining with hæmoglobin it is physiologically indifferent, like nitrogen.

The affinity of carbon monoxide for hæmoglobin is about 250[a] times as great as the affinity of the latter for oxygen. However, if oxygen is administered to a person not too far overcome it will completely replace the carbon monoxide in the hæmoglobin. In this respect pure oxygen acts about five times as rapidly as normal air, which contains approximately 21 per cent of oxygen. From air containing very small percentages of carbon monoxide, less than 0.1 per cent, the blood of a man does not take up enough of the gas to cause distress unless the man breathes such air a long time. If the air contains larger proportions, the blood sooner or later reaches that stage of partial saturation with carbon monoxide that produces helplessness. Haldane[b] makes the following observation:

> The blood of a man will take up about two pints of CO or oxygen. A man at rest breathes about 10 or 12 pints of air per minute, and experiment shows that of the carbon monoxide inhaled about 60 per cent is absorbed by the blood. If a man would breathe air containing 0.1 per cent of carbon monoxide he would absorb 0.007 pint per minute. It would then take him nearly 2.25 hours to absorb a whole pint or produce one-half saturation of the blood, at which stage the limbs would become so weak as to cause them to give way when an effort was made to walk. A man who is walking, however, breathes about three times as much air as a man who is at rest, hence he might absorb a pint within an hour. With 0.2 per cent of carbon monoxide the time would be one-half as long, with 0.3 per cent, one-third as long, etc.

If a man who has breathed mine air containing carbon monoxide and has retired to fresh air to recuperate, again enters workings containing this gas before the carbon monoxide has entirely been displaced from his blood, he feels the effects of the gas in less time than when he entered the workings before.

The experience of those who have been partly poisoned by carbon monoxide seems to teach that usually much pain or distress does not precede collapse. One of the first symptoms is weakness of the limbs and dimness of eyesight. For some time after resuscitation, however, there may be severe headache, or even epileptic seizures and other serious ailments.

Poisoning by carbon monoxide can take place very suddenly. For instance, a man in a mine may quickly pass from a place containing such a small quantity of the gas that he has experienced no distress into a place containing a larger quantity where, because of the already partially saturated condition of the blood, he will quickly succumb. Also, the action of the poison may be accelerated by increased exertion, such as climbing a steep incline or ladder, or lifting heavy weights.

---

[a] Haldane, J. S., Causes of death in colliery explosions and underground fires. Report to the Secretary of State for the Home Department. 1896.

[b] Idem, p. 17.

Generated on 2024-09-28 10:55 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

CHEMICAL TESTS FOR CARBON MONOXIDE.

The author has by the aid of a portable gas-analysis apparatus made tests of the air in mines after explosions and fires and has thus ascertained on the spot the composition of the atmosphere in the workings. Because of the time required to make such tests and the need of the services of a person with some knowledge of gas-analysis apparatus, chemical tests of the atmosphere in a mine immediately after a disaster are not made as often as they should be. Another reason for omitting them is that quick chemical tests for small quantities of carbon monoxide are not made as successfully as are chemical tests for methane, carbon dioxide, and oxygen.

Perhaps the best chemical test for carbon monoxide, in that other gases do not interfere and very simple apparatus is required, is by the use of blood diluted with water to a buff-yellow tint. This test, in the author's experience, is capable of distinctly showing as little as 0.03 per cent of carbon monoxide in the atmosphere. The method of procedure is as follows:

One or two drops of blood drawn from the finger are diluted with water until equal portions of the solution placed in 100 c. c. test tubes have a buff-yellow color. One of the tubes is taken into the mine, and at the place where the air is to be tested about 50 c. c. of the blood solution is poured out, the mine air taking its place. The tube is then corked, taken to the surface, and gently shaken for 10 minutes. If the air contained carbon monoxide the pink color caused by the presence of carbon monoxide hæmoglobin is detected by comparing the solution with the normal blood solution in the other tube.

A fresh active solution of cuprous chloride may be used instead of blood for examining air for carbon monoxide. According to the author's experience, the use of such a solution, if the apparatus is precise and is properly manipulated, will show proportions of carbon monoxide harmful to a rescue party.

THE USE OF MICE AND BIRDS.

EXPERIMENTS WITH MICE.

In the author's opinion the use of birds and mice is superior to chemical tests for carbon monoxide in that the test is quickly made, requires no technical experience, and is sufficiently exact.

Two or three mice or small birds can be placed in a cage and carried into the mine with an exploring party. Because the rate at which chemical changes occur in them is enormously greater than it is in a man, they show symptoms of poisoning far sooner. Haldane [a] states that a mouse weighing one-half an ounce consumes about 15 times as much oxygen as one-half ounce of the human body would

[a] Colliery Guardian, vol. 98, Dec. 17, 1909, p. 1251.

Generated on 2024-09-28 11:07 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

consume in the same time. With 0.1 per cent of carbon monoxide in the air, Haldane found that about two hours elapsed before giddiness, etc., began to appear in a man at rest, and, according to an analysis of the blood, exposure for another half hour would have sufficed to produce practical disablement. A mouse became giddy in 10 minutes. With 0.6 per cent of carbon monoxide in the air, all of the animals tried became helpless in two minutes and rapidly became comatose or died, whereas a person breathing the mixture was entirely unaffected even after 10 minutes. An examination of this person's blood showed that it was one-fourth saturated.

In experiments at the laboratory of the Pittsburgh station of the Bureau of Mines white mice were placed in air containing the following percentages of carbon monoxide: 0.16 per cent, 0.2 per cent, 0.33 per cent, 0.46 per cent, 0.37 per cent, and 0.77 per cent. The mice were placed under a tight glass bell jar having a capacity of 10 liters, into which carbon monoxide had previously been introduced. The atmosphere inside the jar was thoroughly mixed and sampled twice during the experiment, the samples being taken from different points in order to make sure that the content of carbon monoxide was uniformly distributed. The samples were analyzed by combustion of the carbon monoxide in an apparatus with which duplicate analyses agreeing within 0.01 per cent could be performed.

An analysis of the air in the jar at the end of one hour showed that the oxygen content had been depleted 1 per cent, due to the breathing of the mouse, or not enough to affect the air. In air containing 0.16 per cent of carbon monoxide, a mouse showed signs of sluggishness in about six minutes, but this sluggishness, judged by outward manifestations, did not increase to any great extent up to the time the mouse was taken from the jar two hours later. The animal's rate of breathing had dropped from a normal of 160 respirations to about 120 respirations per minute. The mouse did not evince such signs of distress as would serve, if the mouse were carried into an atmosphere containing carbon monoxide, to indicate in one hour's time the presence of 0.1 per cent of the gas.

In air containing 0.2 per cent of carbon monoxide a mouse suffered partial collapse in 15 minutes and showed decided symptoms of distress in eight minutes. At the end of an hour it had not lost all muscular power. It died in two hours.

In air containing 0.31 per cent of carbon monoxide a mouse suffered partial collapse in seven and one-half minutes and showed decided symptoms in about four minutes; but 35 minutes had elapsed before it lost all muscular power and ability to turn over when placed on its back. After removal from the bell jar, the mouse was seemingly in normal condition again in about two hours.

In air containing 0.46 per cent of carbon monoxide a mouse gave decided signs of distress in two minutes; staggered around and

Generated on 2024-09-28 10:58 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

showed partial collapse in four minutes; and in six minutes had lost all muscular power.

In air containing 0.57 per cent of carbon monoxide a mouse showed decided symptoms of distress in one minute, partly collapsed in two minutes, lost all muscular power in seven minutes, and died in 16 minutes.

In air containing 0.77 per cent of carbon monoxide a mouse showed distinct signs of distress in one minute. It lost all muscular power in five and one-half minutes and died in 12½ minutes.

The experiments showed that in air containing the smaller percentages of carbon monoxide the mice displayed varying degrees of activity up to the time they exhibited pronounced distress. Of course, the value of the tests in exploring mines depends upon the warning that the mice give while they are being affected by the carbon monoxide, and it is especially desirable that their actions should indicate the presence of extremely small proportions of carbon monoxide, so that men will have ample time to retire from an atmosphere that contains such proportions of the gas. In the experiments it was found that in small quantities of gas and under like conditions, one mouse might clearly exhibit signs of distress whereas another might become comatose without showing distress so distinctly. Consequently, in using the test, the mouse should be closely watched, and a man not wearing breathing apparatus should retire at once from any part of a mine where the atmosphere distresses a mouse. It is advisable to carry at least three mice at a time into a mine, and to prod them slightly if they remain too quiet, in order to observe them in action.

A man when he exerts himself by carrying heavy objects, climbing ladders, or running consumes in a given time more oxygen and also more carbon monoxide than when he rests. Consequently, a man at work might feel symptoms of carbon-monoxide poisoning that would not be clearly shown by a mouse confined in a cage in the same atmosphere. In an atmosphere containing the small quantities of carbon monoxide usually found in mines after explosions and mine fires, a person may be able to go a long distance without experiencing much inconvenience. On the return trip, however, the symptoms may become so aggravated that considerable difficulty may be experienced in getting to the base of operations or to the surface.

EXPERIMENTS WITH BIRDS.

Because mice may be slow in responding to the presence, in the mine air, of such small percentages of carbon monoxide as would cause distress to a man at work, experiments similar to those performed with mice were tried with birds. Canaries were confined in a bell jar in atmospheres containing the following percentages of car-

Generated on 2024-09-28 10:58 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

bon monoxide: 0.09 per cent, 0.12 per cent, 0.15 per cent, 0.2 per cent, and 0.29 per cent.

After an exposure of one hour to an atmosphere containing 0.09 per cent of carbon monoxide, a bird was not affected to such an extent that it would, if carried into a mine, indicate by its actions the presence of that proportion of carbon monoxide. Only by close observation could one detect that the bird at the end of an hour felt slightly distressed.

With 0.12 per cent of carbon monoxide in the atmosphere of the bell jar, a bird did not show clearly symptoms of being affected. In about 15 minutes it had lost its liveliness and thenceforth remained comparatively quiet. The bird did not fall from the perch, but close observation showed that it was decidedly weaker at the end of the hour than was the bird placed in air containing 0.09 per cent of carbon monoxide.

In air containing 0.15 per cent of carbon monoxide, a bird evinced symptoms of slight distress in three minutes. It gasped, gradually became weaker, swayed, and at the end of 18 minutes fluttered from the perch. At the end of an hour it had not lost all muscular power, but showed symptoms of extreme weakness.

In air containing 0.2 per cent of carbon monoxide, a bird showed pronounced signs of distress in one and one-half minutes; it became very unsteady in three minutes, and fell from the perch in five minutes. After it was taken from the jar it regained its feet in two minutes and appeared to be in normal condition in five minutes.

In air containing 0.29 per cent of carbon monoxide, a bird fell from the perch in two and one-half minutes. When placed in fresh air again it had almost revived in five minutes.

SUMMARY.

The following table shows the relative susceptibilities of mice and canaries to carbon monoxide poisoning:

Effect of CO on mice and canaries.

Mice.		Canaries.	
Per cent CO.	Effect.	Per cent CO.	Effect.
0.16	Very slight distress at end of hour.....	0.09	Very slight distress at end of hour.
.2	Distress in 8 minutes; partial collapse in 15 minutes.	.12	Weaker at end of hour than after exposure to 0.09 per cent.
.31	Distress in 4 minutes; collapse in 7½ minutes; lost muscular power in 35 minutes.	.15	Distress in 3 minutes; fell from perch in 18 minutes.
.46	Distress in 2 minutes; collapse in 4 minutes.	.20	Distress in 1½ minutes; fell from perch in 5 minutes.
.57	Distress in 1 minute; collapse in 2 minutes; muscular power lost in 7 minutes; death in 16 minutes.	.29	Fell from perch in 2½ minutes.
.77	Distress in 1 minute; muscular power lost in 6½ minutes; death in 12½ minutes.	.....	

Generated on 2024-09-28 10:57 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

These tests show that canaries may be better than mice as indicators of the presence of noxious gases in the atmosphere of mines, since they more quickly show signs of distress in the presence of small quantities of carbon monoxide. In addition the symptoms of poisoning in birds are much more clearly defined. A bird sways noticeably on its perch before falling, and its fall is a better indication of danger than is the squatting, extended posture that some mice assume without much struggling, attempts to walk, or other preliminary symptom of poisoning. Consequently birds not only give more timely warning of the presence of small quantities of carbon monoxide; but exhibit symptoms that are more easily noticed by exploring parties.

RELATIVE SUSCEPTIBILITY OF MEN AND BIRDS.

In order to determine for himself the relative susceptibility of men and birds to the action of carbon monoxide, the author performed the following experiment:

A gas-tight chamber, having a capacity of 80 cubic feet, was constructed. Into this chamber sufficient carbon monoxide was introduced to produce an atmosphere containing 0.25 per cent of the latter. The author entered this atmosphere, taking with him canary birds and pigeons. The canary birds evinced distress in one minute and fell from their perches in three minutes. The pigeons only showed slight signs of distress in 11 minutes. The author remained in the atmosphere for 20 minutes, and at the end of that time only suffered a slight headache, although later he became ill. The illness lasted several hours and was accompanied by nausea and headache.

The experiment shows that small birds are much more susceptible to the action of carbon monoxide than are men, and demonstrates the desirability of using small birds, such as canaries, rather than larger ones, such as pigeons.

In company with other persons, the author has also witnessed practical demonstrations of the usefulness of canary birds in exploring mines after explosions had occurred therein. The following analysis shows the composition of the air about 200 feet beyond the point at which a canary bird collapsed. The bird was carried by an exploring party without breathing apparatus. A miner's lamp would burn in this atmosphere, which is typical of those that have caused deaths in rescue parties, and would give no warning of the presence of the deadly white damp.

Generated on 2024-09-28 11:00 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

Composition of a mine atmosphere rendered dangerous by white damp.

Analysis of atmosphere.		Analysis differently stated.		
CO_2	1.49	Air	Oxygen	18.25
O_2	18.25		Nitrogen	69.07
CO	.60		Carbon dioxide	.03
CH_4	1.25	Black damp	Nitrogen	9.05
H_2	.29		Carbon dioxide	1.46
N_2	78.12	Methane		1.25
		White damp		.60
		Hydrogen		.29
	100.00			100.00

A sample of the atmosphere was not obtained at the exact place where the bird collapsed, but was taken at the face of a heading 200 feet beyond and close to what was supposed to have been the seat of the explosion. The exploring party was cautiously advancing along the heading when the bird collapsed; the members of the party immediately retreated without themselves feeling any distress. The bird quickly revived when placed in better air. About one hour later a helmeted party advanced to the face of the heading and collected the sample of air mentioned. The sample was obtained 18 hours after the explosion and before ventilation had been restored in this part of the heading. The carbon monoxide content of the air at the place where the bird collapsed is problematical, but certainly was less than 0.60 per cent, because the air was purer at places in the heading farther back from the face. As a rough guess, the carbon monoxide content may be placed at 0.20 or 0.30 per cent.

The following analysis shows the composition of the atmosphere in an entry that had been more or less traversed by exploring parties for several hours prior to the taking of the sample:

Composition of atmosphere in an entry traversed by exploring parties.

CO_2	0.31
O_2	20.51
CO	.04
CH_4	.20
H_2	.00
N_2	78.94
	100.00

One member complained of not feeling well at the time the sample was collected, but in prior exploration work he had probably breathed for several hours air containing small proportions of carbon monoxide. Hence, his symptoms were to be attributed to the cumulative effect of the air previously breathed rather than to the immediate action of the small proportion of carbon monoxide shown in the sample.

Generated on 2024-09-28 11:00 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

Another feature of the use of birds in exploring mines remains to be considered. A mine atmosphere may be so deficient in oxygen as to extinguish a lamp flame and yet may not contain so little oxygen, or so much carbon monoxide, as to cause distress to birds. In exploring a mine after an explosion a party including members of the Bureau of Mines encountered an atmosphere that, as shown by analysis of a sample, contained the following gases:

Composition of an afterdamp.

CO_2	4.10
O_2	13.64
CO	.00
H_2	.00
CH_4	1.20
N_2	81.06
	100.00

The party was not equipped with breathing apparatus but carried safety lamps and birds. When it entered this atmosphere the lamps were extinguished (an oil lamp goes out in air containing less than 17 per cent oxygen), but neither the men nor the birds showed signs of distress.

In regard to the oxygen deficiency required to cause distress in men, Haldane [a] says:

When the oxygen percentage of air is gradually reduced by absorption of the oxygen, or (what is exactly the same thing) by addition of nitrogen, very little may be felt before the occurrence of impairment of the senses and loss of power over the limbs. If reduction is gradual, and the symptoms be carefully watched, it will be noticed that at about 12 per cent of oxygen, i. e. with a reduction of 9 per cent, the respirations become just perceptibly deeper. At 10 per cent the respirations are distinctly deeper and more frequent, and the lips become slightly bluish. At 8 per cent the face begins to assume a leaden color, though the distress is still not great. With 5 or 6 per cent there is marked panting, and this is accompanied by clouding of the senses and loss of power over the limbs, which would probably end sooner or later in death. It is probable that any sudden exertion made in air markedly deficient in oxygen may lead to temporary loss of consciousness, so that sudden efforts should be avoided in all cases where, through accident or necessity, a man is in an atmosphere which will not support light, and in such a position that he might fall into worse air or otherwise injure himself. When air containing less than 1 or 2 per cent of oxygen is breathed, loss of consciousness, without any distinct warning symptoms, occurs within 40 or 50 seconds. Loss of consciousness in air deprived of oxygen is more rapid than in drowning or strangling, since in the former case not only is the supply of fresh oxygen cut off, but the oxygen previously in the lungs is rapidly washed out. Loss of consciousness is quickly succeeded by convulsions, which are followed by cessation of the respirations. The heart still continues to beat, in the case of cats and dogs, for from two to eight minutes; in man this period is probably

[a] Haldane, J. S., The causes of deaths in colliery explosions and underground fires. Report to the Secretary of State for the Home Department, 1896, p. 15.

Generated on 2024-09-28 11:00 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

longer, for it seems to be the general rule that the larger an animal is the longer it will resist asphyxiation. So long as the heart is beating, however feebly, animation may be restored by artificial respiration. This may require to be continued for a considerable period, as the after effects of deprivation of oxygen are very serious, and the respiratory center may not recover for some time.

The above statement shows why the atmosphere previously mentioned put out the lamps, but did not affect the men, and seemingly had little effect upon the birds. Of course men not wearing breathing apparatus should retreat at once from an atmosphere that extinguishes an oil-lamp flame and thus avoid the possibility of suddenly entering an atmosphere so deficient in oxygen that safe retreat would be difficult. For although birds would undoubtedly indicate in season a deficiency of oxygen sufficient to cause distress to men, if further advance were made, yet immediate retreat from an atmosphere in which a lamp does not burn assures a larger margin of safety.

CONCLUSION.

In bringing these tests to the attention of miners and mine officials the author makes no claim to originality in the use of birds or mice for the purpose of detecting harmful quantities of carbon monoxide in the air of a mine. Dr. Haldane strongly recommends their use. In this country, however, small animals have been used for the purpose described in comparatively few cases. For that reason and because the test is so simple and practical the author has added his observations to the work of Dr. Haldane in order to urge the general adoption of the test in this country. The fact that no series of tests of the comparative merits of birds and mice in atmospheres containing the entire range of small quantities of carbon monoxide had been made is a sufficient reason for the experiments described in the preceding pages. Further, the author's observations indicate that mice are hardly as sensitive to carbon monoxide poisoning as Dr. Haldane's experiments would indicate, and that small birds are better indicators of poisonous atmospheres than are mice.

Generated on 2024-09-28 10:56 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY

PUBLICATIONS ON MINE ACCIDENTS AND METHODS OF MINING.

Limited editions of the following Bureau of Mines publications are available for free distribution. Requests for all publications can not be granted, so applicants should select those publications that are of especial interest. Requests for publications should be addressed to the Director, Bureau of Mines, Washington, D. C.

BULLETIN 17. A primer on explosives for coal mines, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls., 12 figs. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls., 28 figs. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 45. Sand available for filling mine workings in the Northern Anthracite Coal Basin of Pennsylvania, by N. H. Darton. 1913. 33 pp., 8 pls., 5 figs.

BULLETIN 48. The selection of explosives used in engineering and mining operations, by Clarence Hall and S. P. Howell. 1913. 50 pp., 3 pls., 7 figs.

BULLETIN 52. Ignition of mine gases by the filaments of incandescent electric lamps, by H. H. Clark and L. C. Ilsley. 1913. 31 pp., 6 pls., 2 figs.

BULLETIN 53. Mining and treatment of feldspar and kaolin in the southern Appalachian region, by A. S. Watts. 1913. 170 pp., 16 pls., 12 figs.

BULLETIN 57. Safety and efficiency in mine tunneling, by D. W. Brunton and J. A. Davis. 1914. 271 pp., 6 pls., 45 figs.

BULLETIN 60. Hydraulic mine filling; its use in the Pennsylvania anthracite coal fields; a preliminary report, by Charles Enzian. 1913. 77 pp., 3 pls., 12 figs.

BULLETIN 68. Electric switches for use in gaseous mines, by H. H. Clark and R. W. Crocker. 1913. 40 pp., 6 pls.

BULLETIN 69. Coal-mine accidents in the United States and foreign countries, compiled by F. W. Horton. 1913. 102 pp., 3 pls., 40 figs.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp., 1 fig.

TECHNICAL PAPER 21. The prevention of mine explosions, report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.

TECHNICAL PAPER 22. Electrical symbols for mine maps, by H. H. Clark. 1912. 11 pp., 8 figs.

TECHNICAL PAPER 30. Mine-accident prevention at Lake Superior iron mines, by D. E. Woodbridge. 1913. 38 pp., 9 figs.

TECHNICAL PAPER 39. The inflammable gases in mine air, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 2 figs.

TECHNICAL PAPER 41. The mining and treatment of lead and zinc ores in the Joplin district, Mo., a preliminary report, by C. A. Wright. 1913. 43 pp., 5 figs.

TECHNICAL PAPER 47. Portable electric mine lamps, by H. H. Clark. 1913. 13 pp.

TECHNICAL PAPER 58. Action of acid mine water on the insulation of electric conductors, by H. H. Clark and L. C. Ilsley. 1913. 26 pp., 1 fig.

Generated on 2024-09-28 10:57 GMT / https://hdl.handle.net/2027/njp.32101054990377
Public Domain, Google-digitized / http://www.hathitrust.org/access_use#pd-google
Digitized by Google
Original from PRINCETON UNIVERSITY